

INTERNATIONAL SYMPOSIUM ON PROTEIN UTILIZATION  
AUGUST 13-16, 1978  
UNIVERSITY OF GUELPH

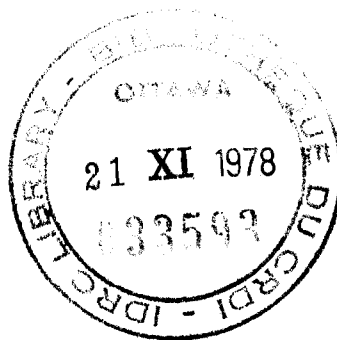
31465<sup>AN</sup>  
IDRC LIBRARY MF  
GIFTS AND EXCHANGES

HUMAN IMPLICATIONS OF PROTEIN UTILIZATION

JOSEPH H. HULSE, DIRECTOR, AGRICULTURE, FOOD AND NUTRITION SCIENCES

INTERNATIONAL DEVELOPMENT RESEARCH CENTRE, P.O. BOX 8500, OTTAWA K1G 3H9

Ten years ago, the United Nations General Assembly adopted and published a report which called for international action to avert the impending protein crisis. More recently, a wearisome debate has gone on between those who insist that no world-wide protein crisis exists or impends and others who are convinced that protein malnutrition continues to present a serious threat to many of the world's least privileged. These contrasting views will be discussed together with a review of methods by which protein may be quantitatively and qualitatively assessed, and research programs that are in progress to reduce the incidence of protein-calorie malnutrition. It will be argued that the statistical, analytical and biological methods used to assess and evaluate protein availability are too imprecise to make possible a reliable judgment of protein adequacy among the world's poorest communities. The semi-arid tropics, including the Sahelian zone of Africa will be used as the focus of discussion.



IDRC-doc-158

ARCHIV  
HULSE  
no. 44

Some of the difficulties inherent in protein evaluation will be cited with reference to the staple crops of the semi-arid tropics including sorghum, the millets, and several food legumes. Research to raise the quality of the diets of the poorest developing nations and to improve the protein composition will be described. Evidence will be presented to suggest that protein availability among the least developed countries may be overestimated and that too little account is taken of post-harvest losses.

Research supported by IDRC to improve the quality of the diet through more productive cropping systems, by improved pastures on marginal grazing lands, by using agricultural wastes in animal feeds, and through village aquaculture will be described.

## HUMAN IMPLICATIONS OF PROTEIN UTILIZATION

Joseph H. Hulse, Director, Agriculture, Food and Nutrition Sciences  
Division, International Development Research Centre, P.O. Box 8500,  
Ottawa, K1G 3H9

In 1780 the brilliant French scientist Lavoisier proclaimed that "La vie est une fonction chimique". Taken literally, the subject of this discourse would embrace the entire chemistry of life; the complexities of protein synthesis, the processes and pathways of metabolism, the physiological utilization of energy, how the whole interdependent system is controlled genetically and hormonally, and by what other influences it is affected for good or ill, in sickness and in health. It is a subject that many of the world's finest scientific minds have spent their whole lives trying to comprehend.

Within the time available, I propose to discuss the subject of the human need for protein under four headings:

- 1) What is protein;
- 2) How much and what kind do we need;
- 3) Where does it come from; and
- 4) Where will it come from in the future.

---

The views expressed herein are those of the author and not necessarily those of the International Development Research Centre

First, two quotations from committees that met forty years apart.

"The movement towards better nutrition in the past has been largely the result of the unconscious and instinctive groping of men for a better and more abundant life. What is now required is the conscious direction towards better nutrition. Such direction constitutes policy. Nutrition policy....must be directed towards two mutually dependent aims: first consumption, bringing essential foods within reach of all sections of the (world) community; second, supply".

The authors then go on to list several essential courses of action to ensure adequate consumption and supply:

- 1) the recognition of nutrition policy as of primary national importance;
- 2) better education on human nutrition;
- 3) a more equitable distribution of income since it is the poorest people who are the most nutritionally deprived.

Such were the recommendations of the League of Nations Committee on Nutrition that met between 1935 and 1937.

Incidentally, that Committee described milk as "the nearest we possess to a perfect and complete food". (League of Nations 1937).

The second quotation comes from the World Food and Nutrition Study by the National Research Council of the United States, published in 1977 which states: "An important cause of malnutrition is the absence of policies and programs to foster the best use of available food supplies... In poor and rich countries alike, governments continually make decisions that affect nutritional status with little or no knowledge of the nutritional consequences. Success in alleviating hunger and malnutrition will depend upon increasing the supply of the right kind of food, reducing poverty, improving the stability of food supplies, and decreasing the rate of population growth" (National Academy of Sciences, USA 1977).

So, forty years later, a second Committee composed of eminent scientists repeats essentially the recommendations of its equally distinguished and competent predecessors.

Plus ça change, plus c'est la même chose!

In order to decide whether we are winning or losing the battle for better universal nutrition, we should perhaps look at the subject in historical perspective. The writers of the books of Daniel and Ezekiel, in the Old Testament, recognized the nutritional benefit of combining legumes with cereals. Pliny spoke of egg white as albumin and in 1777 Macquer, in his dictionary,

used the word albuminous to describe "animal substances which coagulate when heated".

The name "protein" has been attributed to two chemists: the German Mlder and the Swede Berzelius and it first appeared about 1838. It was derived from the Greek word " πρωτειον " meaning that which comes first, and was applied by Berzelius to a range of substances containing nitrogen that he extracted from animal and plant tissue. It is doubtful if either Mlder or Berzelius recognized how appropriate was their chosen name since it was many years later that scientists came to the knowledge that most of life revolves around the activities of proteins. The energy of all living cells goes largely into making proteins and then using them to perform a multitude of diverse functions. In fact, it would be difficult to decide whether proteins have evolved structurally to meet the demands of living plants and animals, or whether our existing life forms have adapted to the structure and nature of the proteins available.

It is indeed remarkable that despite the obvious differences between me and a yeast cell, we are both composed of the same twenty amino acids and the same four purine and pyrimidine bases.

5

In 1854 Lawes and Gilbert discovered the difference in nutritive value between different plant proteins. They fed one pig a diet of barley and a second lentils. They reported that the lentil pig excreted roughly twice as much urea as the pig fed barley.

It was during the 1820s that Bracconot hydrolized first gelatin to isolate glycine and later meat and wool to produce leucine. These were the first two amino acids to be recognized. In 1846, tyrosine was reported by Liebig. The 1860s saw the discovery of serine, glutamic acid and aspartic acid and during the 1890s the basic amino acids lysine, arginine and histidine were described, lysine by Drechsel and the other two by Hedin. It was not until 1935 that Rose and his coworkers completed the amino acid picture by discovering threonine.

It is common knowledge to everyone present that proteins are macro-molecules made up of long chains of amino acids in which the amino group of the first is condensed with the carboxyl group of the second, the amino group of the second is linked with the carboxyl of the third, and so on. These typical linkages were called peptide bonds derived from the Greek word *πέψω* for digestion, , after it was discovered that they could be disrupted by the pepsin present in the stomach's gastric juices.

From the time early in this century when Emil Fischer laboriously joined 18 amino acids together into an octadecapeptide, It was believed that the natural process of protein synthesis within living cells followed a similar pattern of adding one amino acid to another until the chain was complete. Eventually it became evident that such a sequential synthetic system was extremely unlikely given the very large numbers of amino acids and the precise order in which they are arranged within each protein molecule. Haemoglobin consists of a chain of more than 300 amino acid residues and yet the change of just one amino acid for another results in sickle-cell anaemia.

Furthermore, if proteins were constructed by a gradual build-up of peptide sub-units, every cell engaged in active protein synthesis ought to contain peptide fragments in various stages of construction. Yet the analyses of cell contents show that even low molecular weight cell proteins are precise finished molecules, each, like glutathione, with a specific biochemical role.

Therefore, what to early students seemed more preposterous, namely that all the amino acids could come together simultaneously in the right sequence like soldiers forming ranks, we now believe to be closer to the truth, thanks to the remarkable studies of Watson, Crick and Brenner at Cambridge in the 1960s. What appears



to happen is that when all the necessary activated amino acids have been assembled in correct order, according to the genetic code, along the RNA chain in the cell's miniscule ribosomes, all the peptide bonds are formed and the new protein molecule is unpeeled from its RNA template.

One can gain some sense of the odds against such a phenomenon from Synge's calculation. Synge worked out that for a protein of modest size with a molecular weight of 34,000, containing 12 of the 20 amino acids that make up all plant and animal proteins, if only one molecule of each possible isomer were synthesized, the total mass would be  $10^{280}$  grams. We are told that the weight of the earth is only  $10^{27}$  grams. Clearly, though several thousand chemically and physically distinguishable proteins exist in nature, they represent only a very small fraction of what is theoretically possible, a matter which caused concern to many biologists at the time the first moon explorers returned to earth.

In spite of the immense research effort devoted to the study of protein structure and biochemistry, much of it of remarkable brilliance, our knowledge of human protein needs is far from precise, and the methods by which protein nutritional quality is evaluated are for the most part essentially indirect and often empirical.

I was once asked by a young student "are proteins pure substances?". I believe this is impossible to answer in biochemical terms since the very act of extracting a protein from living cells disrupts the delicate balance in which it exists and functions. We possess little knowledge of what form of molecular disruption occurs during fractionation by the various solutions and solvents, ion binding resins, high gravitational and electrical forces which biochemists use to extract and separate cell proteins.

It is certain that the interrelations and connections between proteins and other cell constituents are just as important as the composition of an isolated "purified" sample. Unfortunately, our laboratory techniques are not yet sufficiently refined to observe and measure these intracellular relations. This is not to denigrate the work of the biochemist who seeks to separate and purify protein extracted from living cells; such research is the first step to an eventual greater comprehension of vital protein biochemistry.

Because of the difficulty of isolating and determining the exact structure of natural protein, protein content has to be estimated and evaluated by indirect means. This is true of methods that involve a true chemical reaction, those that depend upon the affinity of some component of the protein for selected

dyes, and such physico-chemical methods as neutron and proton activation and infrared reflectance spectroscopy.

Though first published in 1883, the method of Johann Kjeldahl is still the standard against which all others are compared (Williams 1974). The Kjeldahl method determines nitrogen content and assumes that nitrogen represents a constant proportion in each natural protein source. From the literature it appears that most analysts believe, with the exception of a few cereals including wheat, that nitrogen represents 16% by weight of all animal and most plant proteins. On this basis, the percent protein is calculated by multiplying percent nitrogen by 6.25, the reciprocal of 16 multiplied by 100. By total amino acid analysis, Dr. Tkachuk in Winnipeg and other analysts have clearly shown that nitrogen represents more than 17.5% of most cereals and legumes and therefore the nitrogen to protein conversion factor for grains, pulses and oilseeds lies between 5.3 and 5.7 (Tkachuk 1974). Since almost all reported analyses of, for example, sorghum and the millets and legumes of the semi-arid tropics, are derived from  $N \times 6.25$ , it is probable that published estimates of available protein in that region is exaggerated by up to 10% (Table 1).

More meaningful in nutritional terms than total protein is amino acid composition determined usually by ion exchange chromatography or microbiological assay following acid hydrolysis. This determines the relative proportions of each amino acid present but says nothing of the structure of the protein analyzed or the nutritional availability of its component amino acids.

For many years egg and milk have been the standard reference proteins against which all others were compared. Now that facilities for amino acid analyses are widely available, it is customary to compare the amino acid patterns as analyzed with a standard reference pattern recommended by the FAO/WHO Expert Committee (FAO/WHO 1973) (Table 2).

The amino acid score is calculated by dividing the level of the first limiting amino acid in the test protein by the level recommended in the reference pattern. In sorghum, for example, the first limiting AA is lysine and its average level is about 136 mg/g N. In this case, the amino acid score of sorghum is  $(136 \div 340) \times 100 = 40$  (Hulse et al. 1978).

It is difficult to compare the biological value of different protein sources using human subjects in a normal environment. It is not convenient to fit a farmer with a perfuse liver and an artificial kidney in order to study changes in the pattern of his de-amination and urea excretion cycles between seed time and harvest.

//

Because of the complications of comparing the biological value of different proteins either by analysis or with human subjects, it is customary to use laboratory animals. Savory at St. Bartholomew's hospital in London seems to have been the first to use the rat, which has since become the nutritional biochemists' creature of preference. Where time and facilities permit the animals to be sacrificed, the various organs and tissues can be examined and analyzed post-mortem to determine the relative influence of different protein regimens.

The more commonly used indices of protein quality are those based on rat weight gain and nitrogen retention. Someone has described retention studies as a comparative inventory of the kitchen cupboard and the garbage can. As this suggests, retention studies simply determine the balance between intake and loss through excretion.

One matter of contention is whether iso-nitrogenous diets should be compared at a single protein level, as in the Protein Efficiency (PER) and Net Protein (NPR) ratios or at several different levels as in the Relative Protein Value (RPV) or Slope Ratio Assays. The disadvantage of a single level is that nutritionally poor proteins such as wheat gluten, appear relatively better at low than at high levels of intake.

Because of its widespread use, a comment on the protein efficiency ratio is justified. PER is a comparative ranking index; it is not an absolute measurement of protein quality. PER simply ranks different proteins in a specific experiment according to their influence on rat weight gain. A PER determined at one place and time cannot, with any reliability, be ranked against a PER determined under different conditions at another place and time. In other words, each PER is location and time specific and, unlike the molecular weight of a pure substance, is not an absolute and invariable property or character of each protein source.

Our knowledge and belief in what protein is best for mankind has long been bedevilled by superstition and prejudice. There are those who believe that red meat and red wine make good blood. with the implication that those who prefer chicken and sauterne tend inevitably to anaemia. Anthropologists tell us of primitive people who believe they will grow to resemble whatever they eat and hence avoid the timid chicken but, if cannibalistic, eagerly consume the heart of a brave or pious man.

The physiological benefit that is supposed to result from eating rhinocerus horn does not bear repetition among polite society.

Any discussion of how much protein each of us needs could well be entitled "the protein pendulum". I don't propose to take sides with either of the opposing forces of opinion that seek to push the pendulum one way or the other. Suffice it to say that most of those who advocate "Let them eat more starch" are not themselves at nutritional risk. Since our knowledge of minimum requirement and maximum safe intake for all conditions of human life is so very limited, the wise will prefer caution to dogmatism.

Among early workers, estimates for healthy adults varied between 119 g, prescribed by Playfair in 1865, to 46.5 g per day by Hirshfeld in 1889. Among international expert committees, estimates of daily adult need vary from (a) not less than 1.0 g/kg of body weight to (b) 0.57 g/kg prescribed respectively by the 1935 League of Nations Committee and the FAO/WHO 1971 Expert Committee on Energy and Protein Requirements. These various estimates and the reasoning behind them are critically reviewed in a typically constructive and sympathetic manner by Nevin Scrimshaw in his recent Shattuck and Atwater Memorial Lectures (Scrimshaw 1977ab).

FAO (1973) estimates of the protein available from different food sources in various regions of the world are shown in Table 3. It must be emphasized that these are averages of very uncertain data and it is probable that the ranges and standard deviations

are very large indeed. Consequently, the least privileged, usually the poorest and most vulnerable, have access to average protein intakes considerably lower than those quoted.

Among the poor communities of the less developed countries, the high incidence of infectious diseases and debilitating parasites create a greatly increased demand for protein and energy. During the post-infection recovery, young children may need 40% more protein than is necessary for normal healthy growth.

Indeed it is among young children, particularly those of the poorest and least privileged communities that protein calorie deficiencies are most prevalent (Konczacki 1972; Stanbury and Childs 1974). The word "kwashiorkor" that designates severe protein deficiency comes from Ghana and may be very roughly translated as "The sickness suffered by the young child shortly after being replaced at the mother's breast by the newest arrival".

In recent years many have recognized the difficulty of making a sharp distinction between clinical symptoms indicative of calorie shortage and those of protein deficiency. Because among the poorest of the world's people both are familiar, clinicians now prefer the term "protein-calorie malnutrition" (PCM) which comprehends a broad spectrum of conditions associated with malnutrition.



To determine nutrient balance accurately, subjects are best confined to a metabolic ward or in equivalent controlled isolation. Consequently, among people living and moving within their normal habitat, it is necessary to resort to such indirect indicators as comparative anthropometric measurements, periodic clinical examinations for acute symptoms of distress, mortality and morbidity statistics.

It is my belief that national or regional food balance sheets are of very limited value when one observes the obvious differences in distribution and consumption among years, seasons, countries, communities, families, and even within families in the poor tropical countries. There is strong evidence from many sources to demonstrate a significant relation between income and nutritional well being (Reutlinger and Selowsky 1976). Some of the most acute examples of PCM are to be found among the world's poorest people and it is for this reason that we in the Agriculture, Food and Nutrition Sciences Division of IDRC have directed greatest concern and priority to the semi-arid tropics, most of whose inhabitants have an average per capita income below \$200 (U.S.) per annum.

During the remaining discussion of what protein sources are available and how they might be improved in quantity and quality in the future, I do not propose to discuss the nutritional well being of Canadians and other economically developed countries.

There is no reason why most Canadians need suffer malnutrition provided that present and future governments will legislate rational national nutrition policies and assign a high priority to the food and agricultural sectors of the Canadian economy. To any Canadians who do not know whether they are eating too much, too little or the wrong kinds of food, I would strongly recommend they seek the extremely competent advice of Health and Welfare Canada, and avoid the many self-acclaimed, yet often unqualified, nutritional authorities, each of whom offers his or her own infallible elixir or formula for eternal life on this side of the grave. The popular press would perform a valuable public service by adopting a policy of always seeking competent professional advice before publishing every sensational dietary proposition that comes to their notice.

The poorest people of the tropics rely mainly upon cereals, legumes, root crops and other plant sources for most of their calories and protein and will probably continue to do so for many years in the future. Some of the problems which present themselves to agricultural, food and nutrition scientists can be illustrated by brief reference to sorghum, which is the principal cereal of the semi-arid tropics. The average yield of sorghum throughout the semi-arid tropics is about half a ton of grain per hectare per year. Yet on experimental farms in Africa and

Asia, cultivars that yield better than 8 tons per hectare are in an advanced state of development. It is by no means a simple or straightforward matter to bring together in a single cereal cultivar the gene that will combine high yield, desirable nutritional, agronomic, technological properties together with utility and acceptability. The first problem is to combine a high yielding capacity with functional properties acceptable to the consumer, with desirable nutritional composition, and to persuade the farmers that these superior cultivars can be grown with greater profit and minimum risk.

From a review of all the analyses of sorghum we could find published, the protein ranged from less than 5 to almost 20% on a dry weight basis using 5.7 as the nitrogen to protein conversion factor (Hulse et al. 1978). The first limiting amino acid lysine ranged from 71 to 212 mg/g nitrogen and the median amino acid score appears to be about 40. Assuming an average protein digestibility of 50% and an amino acid score of 40 and using the formula (Table 4) recommended by the FAO/WHO informal group of experts (FAO/WHO 1975), about 5 grams of sorghum protein would be equivalent to one gram of the reference protein.

The proteins present in sorghum as in all seed grains are of two broad classes: first, the structural proteins of the embryo which are of predetermined and invariable composition; second,

the storage proteins of the endosperm, the amino acid composition of which can vary significantly.

Sorghum endosperms can be classified according to several characters. One classification takes account of the relative proportion of corneous and floury components, the former as its name suggests, being hard and brittle like horn, the latter soft and floury. The proportions vary significantly among types, the corneous generally being in greater proportion in the outer layers, the floury predominating near the centre of the endosperm. The floury fraction is lower in total protein but higher in lysine as percent of protein; the corneous is higher in total protein but lower in lysine as percent of protein.

As with all cereal grains, the proportion and composition of the endosperm storage proteins is influenced both by genetic background and agronomic environment and depends upon the ability of the plant to take up nitrogen and transfer it to the seed. Within sorghum populations of similar genetic background, as the percent of protein increases, the percent of lysine in protein decreases, consequently as the amount of protein goes up, the nutritional quality of the protein declines.

Recently, genotypes with a very much higher than average lysine content have been discovered in Ethiopia (Singh and Axtell 1973ab). In common with Opaque-2 maize these genotypes are characterized by an opaque floury endosperm, smaller seeds and a higher free sugar and lipid content.

Even more recently a high lysine character has been induced by chemical mutation using diethylsulphate (Mohan and Axtell 1974; Axtell 1976). The grains of the chemical mutagen are more nearly normal in appearance and the high lysine character seems to be controlled by a simple recessive allele which suppresses prolamine formation in the storage proteins.

Research is in progress in India and at Purdue University to combine either or both of these high lysine genes into a stable genetic background to provide cultivars high in lysine with average protein content, an acceptable grain quality and high yield. Given the success of producing such a combination in high lysine maize, one can be hopeful that these research efforts will eventually combine a higher than average lysine with other essential characters. Another desirable character is a corneous endosperm since sorghums with a floury character are more difficult to process (the endosperm tends to chip or shatter) in the abrasion type grain mills which are gradually finding favour in a number of developing countries. Since the

high lysine genotypes are of the floury opaque character, some measure of compromise will be necessary between nutritional and technological quality.

Among normal sorghums the digestibility of the protein varies widely; in many instances it is reportedly lower than 50% of the digestibility of the standard reference proteins. While a generally inferior nutritional quality and digestibility appear to be intrinsic characters of the protein of many sorghums, both are aggravated in certain genotypes by the high polyphenolic tannin content of the pericarp and/or testa. Only recently has the principal polyphenol in several sorghums been identified as a procyanidin polymer synthesized through the shikimate pathway and typical of others found in plants with a woody habit of growth. It is not known whether this polyphenol or its oxidation products react with dietary proteins, before and/or during the animal's digestion process, through hydrogen bonding, ionic bonds or covalent linkages. It is evident, however, that both protein digestibility and overall digestibility are reduced by sorghum polyphenols, the latter probably as a result of reactions of the tannin with digestive amylases and other vital enzyme systems.

Now that the chemical nature of the polyphenol has been determined, the immediate solution would appear to be to breed for its elimination. However, the high tannin sorghums are

generally more resistant to bird attack, to insect infestation and fungal infection. The ideal objective would seem to be to develop sorghum types with a pericarp high enough in procyanidin content to resist attack yet loose enough to be efficiently separated by abrasion milling. Clearly there is an interesting opportunity for imaginative collaboration between the plant breeder and the cereal technologist.

The polyphenols in sorghum have been extensively studied. There is less certain evidence to suggest the presence of polyphenols in pearl millet and finger millet, and among some of the legumes that carry dark-coloured seed coats. Whether these also inhibit protein digestibility is yet to be determined, but deserves study.

It has been reported in sorghum protein that the ratio of leucine to isoleucine may be critical to nutritional quality. Scientists at the India Institute of Nutrition reported that in humans, dogs and monkeys, pellagra-like symptoms, typical of niacin deficiency, appeared with diets high in sorghum types in which the leucine to isoleucine ratio was higher than 3:1 (Belavady ). The condition, it was claimed, could be alleviated by adding isoleucine. The relation between tryptophan and niacin is well known; but no one outside India appears to have noted any relation between leucine, isoleucine and apparent niacin deficiency.

Another means of characterizing proteins is by solvent fractionation. The classical method for plant proteins is that proposed by Osborne late in the 19th century (Osborne 1924). Osborne's fractions were (1) albumin - soluble in water; (2) globulin - soluble in dilute NaCl; (3) prolamine - soluble in 70% ethanol; (4) soluble glutelin - soluble in NaOH; and (5) insoluble glutelin, the insoluble residue. An interesting feature of many sorghum types is that when protein is subjected to the Osborne solvent sequence, a comparatively large undissolved residue remains. This is true of both high and low tannin sorghums. Consequently, other analysts have proposed a more disruptive sequence of solvents including isopropanol, both alone and in combination with 2-mercaptoethanol followed by strongly alkaline buffers combined with surface active agents (Landry and Moureaux 1970; Mertz 1974).

Unfortunately, for the casual reader, the same fraction names proposed by Osborne, namely albumin, globulin, prolamine and glutelin are used to designate the fractions from many different solvent sequences. Several authors report that as the sorghum seed matures, and as the protein content increases, the relative proportions of albumin and globulin decrease and prolamine increases. Also "high lysine genes" are in truth prolamine depressant genes. It is important to recognize that



albumin, globulin, prolamine and glutelin are not precise descriptions and the nature and proportion of the fractions thus designated will depend upon many factors including the condition of the test sample, the sequence, concentration, period of contact, chemical composition and concentration of each solvent used.

In addition to IDRC's support for research in the various aspects of sorghum improvement described above, we are also supporting studies in Africa, Asia, the Near East and Latin America to increase the yield capability and utility of several food legumes including cowpea, chickpea, pigeon pea, faba beans and lentils (IDRC 1977; Hulse et al. 1977a; Siegel and Fawcett 1976). It is unnecessary to remind this audience that the amino acid compositions of cereal grains and legumes are complementary and that a combination of roughly 2 parts of cereal to 1 of legume provides a protein of good nutritional quality. Unfortunately, because of their comparatively low yield, per capita production of legumes throughout the developing world is declining in relation to cereals. Only in Latin America does the ratio of cereal to legume production approximate 2:1; in Asia it has declined to 9:1 (Hulse et al. 1977b). As with sorghum, a combined effort is required among plant breeders and agronomists to increase yields and food technologists and home economists to devise simple technologies to enable rural processors

in the semi-arid tropics to convert legumes to forms that can be acceptably combined with cereal grains (Table 5).

It seems to be the feeling among some prophets that we should slaughter all farm animals and require the whole world to subsist upon protein entirely derived from plants. I firmly believe that over the next 100 years the proportion of plant protein will increase in the diets of people of both the developing tropics and the developed temperate zones. But the contribution to be made by both land and water-borne animals should not be discounted. Many areas of the world's marginal lands are not suited to the economic production of cereals, food legumes or other plants for human consumption.

Research has shown that many of these marginal areas can sustain productive combinations of tropical grasses and pasture legumes suitable for grazing animals or for harvesting as green or preserved forage. We believe that the research we are supporting in the Caribbean, Latin America and the Near East will confirm that our support for research to this end has not been misplaced (IDRC 1977).

In addition, we believe there are throughout the world immense quantities of agricultural wastes and by-products unacceptable for human consumption but well suited to the feeding of farm animals.

Coffee pulp, the fleshy fruit which surrounds what we call the coffee bean, contains a significant amount of good quality protein but is thrown away in enormous quantities in all coffee growing countries. There is a great wastage of the by-products from the processing of sugar cane, root crops and oilseeds throughout the world which could be inexpensively converted to animal feed. Research supported by IDRC in Latin America, the Near East, Africa and Asia is demonstrating the effectiveness of combining improved pastures on marginal lands with agricultural wastes and by-products in meat and milk production.

The excellent work of Dr. Gregory at the University of Guelph has indicated how carbohydrate may be effectively enriched with protein through fermentation with carefully selected microorganisms. Apart from the continued use of conventional yeasts, I do not believe single cell protein will be a major direct contributor to human diets in the foreseeable future. I am convinced however that Dr. Gregory's work points the way to a much greater use of microbial protein in animal feeds.

One of our greatest hopes for increasing world protein supplies is through aquaculture or fish farming. Several projects IDRC is supporting show spectacular promise for the future of aquaculture in developing countries.

The village pond is a common landmark in every Indian village and the raising of fish in these ponds has been practiced for generations. Until recently, fish yields were comparatively low because of the low stocking density and competition from unwanted species. Research by Indian scientists showed that a readily available oilseed contains an alkaloid which, when applied to ponds, destroys all forms of aquatic animal life but is subsequently degraded to inert substances. Once the pond is clear of unwanted competition, it can be stocked with as many as six different non-competitive species of carp, fertilized by cow dung and super phosphate and supplied with waste vegetable material for the herbivorous species of grass carp. Polycultures of this kind can yield over six tons of fish per hectare per year in village ponds.

There is a serious shortage of fish seed for fish farming throughout Asia, one of the reasons being that the females of many fish species do not readily lay their eggs when in captivity. Ovi deposition can however be induced by injections of crude gonadotropin extracts from the pituitaries of other fish, including the Pacific salmon. Throughout the Philippines and some other countries of Southeast Asia, the milkfish is the most important cultured species and last year, for the first time in history, a female milkfish was induced to spawn by gonadotropin

injection. This breakthrough promises an enormous increase in the quantities of milkfish that can be produced in natural and artificial ponds, in lagoons, and in flooded paddy fields.

In Sabah and Sierra Leone, the tropical mangrove oyster is being grown to marketable size in less than a year by providing it with less crowded conditions than it finds in its natural habitat when attached to a mangrove root. It takes three to five years for oysters to reach acceptable size in temperate waters.

Perhaps the most spectacular promise of all the mariculture projects we are supporting is to be found in the mussel culture research in progress off the coast of Singapore. On ropes suspended below floating rafts, Singapore scientists are producing almost a quarter of a ton of mussels below each square meter of raft. While it is too soon to make such a valid extrapolation, this scale of production is equivalent to 100 tons of protein per hectare of surface water, the significance of which is illustrated by the fact that a good crop of soybeans does not produce much more than one ton of protein per hectare.

The network of aquaculture and mariculture projects supported by IDRC will be described in greater detail in an IDRC publication to be released later in 1978.

All of the protein sources referred to (cereals, legumes, fish and land animals) are traditional and conventional. There exist immense opportunities whereby to produce more abundantly and distribute more uniformly these conventional sources of protein. It is these opportunities we should pursue, particularly among countries of the third world, before we seek to discover and devise unfamiliar and unconventional food forms.

Agricultural scientists are pursuing the goals of increased production with zeal and imagination. Though food scientists have served North Americans admirably (we enjoy a great variety of processing nutritious foods all the year round), food science has contributed less than agricultural science to the needs of developing countries. There is no product of food science to compare with short-straw rice and wheat or with high lysine maize. It is therefore to the post-production system (the sequence that comprehends all stages and activities from the time and place of harvest to the time and place of consumption) that we must now seek to improve.

If I were to name the highest immediate priority for food science, it would be to devise simple and inexpensive systems of preserving and distributing fish in tropical countries. Unless fish can be efficiently preserved soon after it is caught, much of the increased production from aquaculture will inevitably be lost.

The results of several dedicated pioneers, including scientists at the Prairie Regional Laboratory in Saskatoon, show the way to more efficient processing of sorghum, the millets and legumes of tropical origin.

In closing, may I emphasize what I have attempted to illustrate in this fragmentary and macroscopic review of protein for human diets.

Though we are much better informed than we were 25 years ago, there remains much we have yet to learn about how much protein we need; how it can be reliably measured and evaluated; in what form and composition protein is best provided for all conditions of men, women and children; what factors influence the digestion absorption, transport and utilization of protein in the human body; how much protein and of what quality is truly available at all seasons to those in greatest need.

Until we can answer these and many other relevant questions, wise men will think twice before proclaiming that the protein problem is dead and buried.

## R E F E R E N C E S

Axtell, J.D. 1976. Annual report on inheritance and improvement of protein quality and content in Sorghum bicolor (L.) Moench. April 1, 1975 - March 31, 1976. Report No. 12. Purdue University.

Belavady, B. 1977. Nutritive Value of Sorghum. Presented at 1977 International Sorghum Workshop, International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, India.

FAO/WHO 1975. Energy and protein requirements: recommendations by a joint FAO/WHO informal gathering of experts. Food and Nutrition, Vol. I (2), 11-19.

Hulse, J.H., Rachie, K.O. and Billingsley, L.W. 1977a. Nutritional standards and methods of evaluation for food legume breeders. International Development Research Centre TS-7e, Ottawa.

Hulse, J.H., Fawcett, B.D. and Daniels, W.D. 1977b. Protein supplements: world production and trade. In Oilseed and Pulse Crops in Western Canada. Western Cooperative Fertilizers Limited, Calgary.

Hulse, J.H., Laing, E.M. and Pearson, O.E. 1978. The composition and nutritional quality of sorghum and the millets. (In press).



International Development Research Centre, 1977. Agriculture, food and nutrition sciences: the first five years, IDRC 089e, Ottawa.

Konczacki, Z.A. 1972. Infant malnutrition in sub-saharan Africa: a problem in socio-economic development, Cdn. J. of African Studies, VI, iii, 433-449.

Landry, J. and Moureaux, T. 1970. Heterogeneity of the glutelins of maize grain: selective extraction and composition in amino acids of the three fractions isolated (in French). Bull. Soc. Chimie Biol., 52, 1021-1037.

League of Nations, 1937. The relation of nutrition to health, agriculture and economic policy. League of Nations.

Mertz, E.T. 1974. Breeding for improved nutritional value. Cereal Science Today 19 (9), 385.

Mohan, D.P. and Axtell, J.D. 1974. Chemically induced high lysine mutants in Sorghum bicolor (L.) Moench. Agronomy Abstracts 66.

National Academy of Sciences, USA, 1977. NRC world food and nutrition study: the potential contributions of research. National Academy of Sciences.

Osborne, T.B. 1924. The vegetable proteins. Longmans Green, New York.

Reutlinger, S. and Selowsky, M. 1976. Malnutrition and poverty: magnitude and policy options. World Bank Staff Occasional Papers 23, John Hopkins University Press.

Scrimshaw, N.S. 1976. Shattuck lecture: Strengths and weaknesses of the committee approach. An analysis of past and present recommended dietary allowances for protein in health and disease. New Engl. J. Med. 294, 136-142; 198-203, Jan. 15 and 22.

Siegel, A. and Fawcett, B. 1976. Food legume processing and utilization. International Development Research Centre TS1, Ottawa.

Singh, R. and Axtell, J.D. 1973a. High lysine mutant gene (h1) that improves protein quality and biological value of grain sorghum. Crop Science 13 (5), 535-539.

Singh, R. and Axtell, J.D. 1973b. Survey of world sorghum collection for opaque and sugary lines. In Inheritance and Improvement of Protein Quality and Content in Sorghum. Research Progress Report No. 10, 1-22, Dept. of Agronomy, Purdue University, USAID.

Stanbury, J.B. and Childs, J.A. 1974. Health, nutrition and population, Annex 2. Massachusetts Institute of Technology. Massachusetts.

Tkachuk, R. 1974. In Nutritional Standards and Methods of Evaluation for Food Legume Breeders, J.H. Hulse, K.O. Rachie and L.W. Billingsley (eds.), International Development Research Centre Ts-7e, Ottawa.

Williams, P.C. 1974. Errors in protein testing and their consequences. Cereal Science Today, 19 (7), 280-282; 286.